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FINAL REPORT

OPTIMIZING PASTURE PRODUCTION BY USING MIXTURE OF NATIVE SHRUBS AND LEGUMES IN SOUTHWESTERN SASKATCHEWAN

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Optimizing Pasture Production by Using Mixtures of Native Shrubs and Legumes in Southwestern Saskatchewan

Prepared by
M.P. Schellenberg, M. R. Banerjee and P.G. Jefferson
SPARC-AAFC

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Abstract

Late season grazing has been identified as a method of dramatically decreasing the cost of beef production in southwestern Saskatchewan. One potential method of improving late season grazing would be to take advantage of native shrubs and legumes which maintain a higher nutritional value at this time of year. In order to develop a potential forage source with these species we require a clearer understanding of optimum mixtures of shrubs and legumes. A greater understanding of the processes occurring in the soil and its impact on plant biomass is also required. The objective therefore of this project was to provide this information.

Field study
A field study was conducted to determine the best species mix and to develop a better understanding of the impacts of the species on forage production and soil attributes. Treatments consisted of five monocultures (two shrubs: winterfat (*Krascheninnikovia lanata*), saltbush (*Atriplex gardneri* syn. *A. nuttallii*) and three legumes: alfalfa (*Medicago sativa*), American vetch (*Vicia americana*) and purple prairie clover (*Petalostemum purpureum*)), six combinations of these species and a control; with four replications. In the field, the winterfat and alfalfa combination was the best. Two and a half years was too short of a period to note changes in soil attributes due to plant species.

Pot study
A greenhouse study was conducted to optimize mixtures of legumes and shrubs for economical pasture production. The first goal was to obtain better understanding of synergy from combinations of legumes and native shrubs. The second goal was to estimate the changes in quality of soil caused by growing legumes and shrubs in monocultures or mixtures. The treatments were exactly the same as in the field study. Data on plant biomass, forage quality and soil quality parameters indicate that legume and shrub mixtures of Alfalfa + Winterfat and/or Alfalfa + Saltbush can provide diversified forage mixtures, extend grazing periods and produce higher yields with enhanced or similar forage quality than when grown separately.

Natural plant community sampling
With a single sampling date, no significant trend and/or changes were observed in the soil parameters in the GNP and PFRA sites due to the establishment of the shrubs.

Executive Summary

In the spring of 1998 shrub and legume plots, monocultures and two species mixes were established. In the fall of 1998 a greenhouse pot study with the same treatment combinations was also begun. The visual observations in the field plot study and the data from the greenhouse pot study indicates that a pasture with a mixture of shrubs and legumes (Alfalfa + Winterfat and /or Alfalfa + Salt bush) can potentially provide diversified forage mixture, extend grazing periods, produce higher yields than when grown separately with enhanced forage quality. However, a long-term field study is needed before the full benefits can be established satisfactorily.

Technical Report

Objectives:

1) to optimize mixtures of shrubs and forbs for economical production of pasture, and
2) to obtain better understanding of mutual benefit of combinations of native forage shrubs and legumes to further improve their productivity.

Methods and Materials:

This research consists of two portions, each has a different emphasis. The first study consists of growing different mixtures of shrubs and legumes. Shrub species include: winterfat and salt bush; legumes include: alfalfa, prairie clover and american vetch. Treatments were applied to plots distributed in a randomized complete block design (Figure 1). All plots were rototilled before transplanting (May 29, 1998) shrub seedling or seedling legumes. The seedlings were grown from seed stock at the Semiarid Prairie Agricultural Research Centre.

Treatments consist of five monocultures, six combinations and a control; with four replications.

1. Alfalfa (Alf)
2. Prairie clover (PrCl)
3. Vetch
4. Winterfat (Wf)
5. Salt bush (Sb)
6. Alfalfa + Winterfat (Alf + Wf)
7. Alfalfa + Salt bush (Alf + Sb)
8. Prairie clover + Winterfat (PrCl + Wf)
9. Prairie clover + Salt bush (PrCl + Sb)
10. Vetch + Winterfat (Vetch + Wf)
11. Vetch + Salt bush (Vetch + Sb)
12. Control treatment - no seedlings in strip.

Total number of treatment plots is forty eight. The area of each plot is 9 m X 3 m with two rows of shrub and/or legume transplanted and the rest area are growing well established Russian wildrye. Visual observations of establishment and growth of shrub/legume plants were made at different times (e.g. Plates 1 and 2).

The second study objective has an emphasis on the changes in soil quality caused by growing shrubs and legumes. Soil samples were collected before the experiment initiated. Initial soil characterization was done (Table 1). Soil samples were again collected from plots with established stands during fall of 1999 and fall of 2000. The soils were stored in cold room (4 °C) and then sent to the laboratory for soil quality analysis. Soil moisture content were monitored every two weeks initially and later on a monthly basis by Time Domain Reflectometer (TDR).

Deviation - Due to the poor growth of the shrub/legume transplants in the field in the first year of the study (1998) only plant height was measured. Due to the same reason no fall soil sampling was done to see the changes in soil quality in the first year of study. Due to no growth of salt bush and vetch, and grazing of alfalfa, winterfat and prairie clover by wildlife, collection of biomass data was not possible in the second year of trial. However, visual observations were made at different times for both the monocultures and combinations during 1999 and 2000. Due to poor establishment of the stands in general, only alfalfa and winterfat plant biomass were determined. Forage quality analyses also were done on alfalfa and winterfat samples grown in monocultures and in different combinations.

Additional Study -

A) *Pot study:* A pot study was conducted in the green house (16 hour photo period, 8 hour dark; 24 .C during day and 18 .C during night) to determine optimal mixtures of legumes and shrubs using a Brown soil (Swinton silt loam) obtained from the same experimental field as the field study. The simulated pot study was conducted using the same 12 treatments as the field study. However, the experiment was laid in a completely randomized design with three replications to give a total number of thirty-six pots. Each pot contained 2 kg of soil. Legume and shrub seedlings (2-weeks old) were transplanted into the appropriate pots in the last week of August, 1998 and the seedlings came from the same seed lot as the field experiment. Four plants were transplanted in each pot. For monocultures, each pot contained four plants of a single species and for the mixture treatments, two plants per selected species. Visual observations were made at different times of establishment and growth of shrub/legume plants (Plates 3 and 4). Plant biomass was measured as fresh and dry weights after the first cut (November 25, 1998), second cut (January 27, 1999), third cut (March 22, 1999), fourth cut (May 4, 1999) and fifth cut (June 14, 1999) depending on the full bloom stage of alfalfa. Normally the harvest of forage would occur when winterfat had reached set, much later than bloom stage of alfalfa. The harvest was done at this stage for the purposes of the pot study. Plant biomass samples were dried, bulked and sent for forage quality analyses. Forage quality (crude protein, P content, Ca content, organic matter digestibility (OMD), acid detergent fibre (ADF) and neutral detergent fibre (NDF)) of the biomass was analyzed and at the end of fifth harvest soils were destructively sampled to assess the changes in the soil quality parameters.

Statistical analyses of the data were performed by the analysis of variance and means comparisons of the treatment effects. Data were analyzed using SAS statistical software (SAS Institute, Inc. 1989). If a significant F value was obtained, then least significant difference (Fisher LSD) was determined among treatment means.

B) *Established shrubs and soil quality study:* Two preliminary collaborative studies on the impact of established shrubs (Winterfat and Saltbush) in soil quality were initiated between SPARC-AAFC and Grassland National Park (GNP) & SPARC-AAFC and Prairie Farm Rehabilitation Administration (PFRA). Control and established shrubs impacted soil samples were collected from the following sites:

1. GNP Salt bush site near Val Marie
2. PFRA Winterfat site at Masefield Community Pasture
3. PFRA Winterfat site at Newcombe Community Pasture
4. PFRA Saltbush site at Big Stick Community Pasture
5. PFRA Saltbush site at Bitter Lake Community Pasture

Soil samples were air dried and sieved for soil physical and chemical analysis in the SPARC Soil Analytical Laboratory.

Results and Discussion:

Field Plot Study - Figure 2 shows the soil moisture content at the field plots during the growing season in 1998, 1999 and 2000. There was no significant difference in soil moisture between the plots under various treatments. However, in 1998, the plots had significantly higher moisture content (16-18%) during the earlier part of July than later part of July, August, September and October. The later part of the growing season was dry (4-8% soil water i.e. below permanent wilting point for alfalfa) for 1998 and 1999. The soil water in 1999 was similar to 1998 but in general the growing season precipitation was much higher. This parallels the precipitation data, with 1999 having a wetter spring while 2000 was wetter yet with precipitation occurring throughout the growing season (Figure 3). The soil moisture data indicated no spring recharge was in evidence by June 1999 while in June 2000 there was increased moisture (Figure 2). The initial establishment of the shrub/legume plants were acceptable, later on vetch and saltbush were struggling to grow. In general, growth of the plants were poor in the initial year of study. Vetch were completely dormant with only a few individual plants breaking dormancy in 2000 and growth of saltbush was poor overall. As a result, biomass determination was not done and only plant heights were measured (Table 2). However, no vetch data (alone or in combination) were presented in the Table 2. In fact, salt bush and vetch did not grow in the second or third year of study (Figure 4 and 11). Only alfalfa, winterfat and prairie clover established both as monocultures and combinations (Figure 4 and 11).

When comparing plant heights for 1999 (Table 2) and dry matter yields for 2000 (Table 5) alfalfa production increased in plots with winterfat present. The winterfat plant heights and dry matter production decreased indicating a mismatch in competitive ability. A subsequent study with a 30 cm separation (not reported) between alfalfa and winterfat indicated improvements in winterfat production. A recently initiated study will examine the benefit of greater row separation (50 cm). Another contributing factor to poorer winterfat performance may have been the close proximity (15 cm) of mature Russian wildrye. Russian wildrye is known as one of the more aggressive grasses for resource acquisition. Despite a small contribution to biomass addition of winterfat appeared to increase crude protein and Ca (Table 6) providing a better forage product.

Soil attributes did change from initial (Table 1, 1998) to later years (Table 7, 1999 and 8, 2000). The changes were due largely to decomposition of detritus from rototilling out a row of Russian wildrye. The decay process released carbon and nitrogen the first year as seen in Table 7 with a decrease in 2000 (Table 8). The changes from breakdown of the material masked any

possible changes due to the species studied. It is also generally felt among the Soil Science community a two year period is insufficient time to note changes in macro nutrients (N,P, S) or C which are not also masked by weather effects.

Pot Study - Figures 5 and 6 represent the fresh and oven dry weights of plant biomass in the legume-shrub pot study after the first cut. Based on the first cut, the mixture treatments in general produced more biomass than the monocultures. The Pr Cl + Wf treatment did not enhance the biomass production compared to the combined production of prairie clover alone and winterfat alone. In the Alf + Wf and Alf + Sb treatments, production of alfalfa was increased to the extent that even though the production of winterfat and saltbush have been decreased but the total production of the combinations were higher than the monocultures. Another noteworthy observation might be related to the shrub production. The Pr Cl + Sb and Vetch + Sb combination produced more shrub (saltbush) than legumes. Although the production was not as high as Alf + Wf or Alf + Sb combinations, however, these observation might have a bearing on the composition of the forage stands. In addition, if we look at the fresh weights and dry weights of saltbush biomass we might find that saltbush contained maximum amount of water in its biomass which might be a interesting observation in relation to the semi-arid forage production.

In the pot study, based on all five cuts, the mixture treatments in general produced more biomass than the monocultures (Figure 7). However, the Pr Cl + Wf and Vetch + Sb treatments did not enhance the biomass production compared to the combined production of their respective monoculture treatments. In the Alf + Wf and Alf + Sb treatments, production of alfalfa was increased to the extent that even though the production of winterfat and saltbush have been decreased the total production of the combination were higher than the monocultures (Figure 7). In addition, only Alf + Wf and Alf + Sb treatments showed positive or no negative impact on the biomass production on oven dry weight basis (Figure 8). The Pr Cl + Sb and Vetch + Sb combination produced more shrub (salt bush) compared to the respective legumes. Although the production was not as high as Alf + Wf or Alf + Sb combinations, however, these observation might have a bearing on the composition of the forage stands (Figures 6 and 7).

Forage quality (protein yield and P content) were increased or nearly maintained at the same level in the Alf + Wf and Alf + Sb treatments compared to the combined forage quality of their respective monoculture treatments (Figures 9 and 10). The Ca content, OMD, ADF and NDF data are not yet available from the laboratory.

No significant changes were found at this time in soil quality parameters measured by growing legumes and shrub in mixtures in the pots (Table 3). However, it should be noted that these are only one year greenhouse pot study data.

Establishment and growth of legume/shrub plants in the pots at different growth stages were visually observed. Based on the five bulked cuts, the combination treatments had significant (P . 0.02) effects on plant biomass production on dry matter basis (Figure 1). Combination treatment of Alf + Wf showed positive significant (P . 0.05) effect and Alf + Sb treatment showed no negative significant (P . 0.05) impact on the plant dry matter yield. A multi-year experiment

carried out in southwest Saskatchewan indicated that the yield from the mixture of legume and grass was always higher than growing grass alone (Leyshon 1978). Enhanced growth of the grass could be related to the increased available N supplied by the legume, which is a N-fixing plant. Similar synergistic phenomenon might have occurred between the legume (alfalfa) and the shrubs. In the Alf + Wf and Alf + Sb treatments, production of alfalfa was increased to the extent that even though the production of winterfat and saltbush have been decreased the total production of the combinations were higher or similar to the respective monocultures' combined production (Figure 1). This might have been due to light competition in the smaller pot surface area because of the more upright vigorous growth of alfalfa compared to the relatively shorter and bushier plants of winterfat or saltbush. Alfalfa growth in Canadian Prairies is often limited by low soil moisture contents. Waddington and Steppuhn (1996), and, Steppuhn and Waddington (1996) reported a 40% increase in alfalfa production when soil moisture was increased using tall wheatgrass windbreaks that trap snow and decrease evapo-transpiration. In a field situation these woody shrubs, winterfat and saltbush, may also be able to serve a similar purpose as the tall wheatgrass windbreaks. Thus, growing a mixture of shrub (Wf or Sb) and legume (Alf) has the potential to maximize the mutual benefit, as legume provides available N to the shrub, and the shrub structure reduces wind speed and conserves moisture. The other combinations (Pr Cl + Wf, Pr Cl + Sb, Vetch + Wf and Vetch + Sb) did not increase the plant dry matter yield over their respective monocultures' combined biomass production. On the other hand, the Pr Cl + Sb and Vetch + Sb combination produced more shrub (saltbush) compared to the respective legumes. Although the production was not as high as Alf + Wf or Alf + Sb combinations, however, these observations might have a bearing on the composition of the forage stands (Figure 1).

Forage quality (protein yield, P content and Ca content) was increased or nearly maintained at the same level in the Alf + Wf and Alf + Sb treatments compared to the combined forage quality of their respective monoculture treatments (Figures 2, 3 and 4). Protein yield, P content and Ca content were increased significantly (P . 0.01) in the Alf + Wf combination whereas in Alf + Sb combination protein yield was increased slightly and no significant changes were observed in P and Ca content . The combinations therefore may provide enough protein, phosphorous and calcium for livestock, but less crude fibre than do principal grasses of comparable growth stage (Smoliak and Bezeau 1967). Thus, they may be used as a potential winter pasture forage which will help in extending the grazing period, resulting in decreased operational costs and greater returns to the livestock producers (Adams et al. 1996). However, no significant (P . 0.05) beneficial changes were found at this time in soil quality parameters measured by growing legumes and shrubs in mixtures in the pots (Table 2). This is most probably due to the limited number of plants in each pot and duration of the investigation. In a long-term field experiment we might find different scenarios for the changes in soil quality parameters. As the restriction of root biomass by the pot dimension (compared to a field study) may have restricted additions of organic carbon in soil although growing Sb in monoculture had positive effect on the soil quality parameters. Nonetheless, this pot study indicated that alfalfa–winterfat / alfalfa-saltbush mixtures might have the potential to increase forage production as well as forage quality.

Established Shrubs and Soil Quality Study - No significant trend and/or changes were observed in the soil parameters in the GNP and PFRA sites due to the establishment of the shrubs (Table 4) at this soil sampling event.

Conclusion: The pot study establishes a potential for mixing shrubs and legumes. With our present level of understanding of the species examined in this study alfalfa and winterfat exhibited the greatest potential. Additional research is required to address agronomic concerns such as appropriate row spacing. With additional basic research other species such as saltbush and purple prairie clover may also prove to be potential species to be included. American vetch seed used for this work showed lack of adaptation. American vetch does grow in the semiarid prairie and remains green throughout the growing season so this species may yet have some potential if a seed source of better adapted seed lot were available.

The time length of this project was sufficient to establish plots for later comparisons of soil attributes. But the time length was insufficient to demonstrate N transfer or C sequestration capabilities of the species in mono- or bi-culture.

Personnel:

Professional:	Dr. M.R. Banerjee
Equipment:	NONE
Project Developed Materials:	Newsletters, articles, public display etc. (please also see Acknowledgments)

Acknowledgments:

1) Listed as source of funding for SPARC Research Newsletter (copy previously attached).
   a) Article published in Western Producers (copy previously attached).
   b) Article published in South West Booster (copy previously attached).
   c) Mentioned in Grain News (copy previously attached).
   d) Article published in Saltshaker (copy attached).
2) Poster presentation in Crop Science Society of America Meeting, 1999 (copy previously attached).
3) Listed as source of funding at the BDF Board presentation, 1999.
4) Public Display at the Research Centre (SPARC).
5) Listed as source of funding at the BDF Board presentation, 2000.
6) Listed as source of funding at the SPARC Annual Program Review, 2000.
7) Presentation in Soils and Crops 2000 (Copy of Proceedings attached)
8) Paper presented at the Forage-Ruminant Workshop organized jointly by the Eastern Forage Ruminant Network (EFRN) and the Western Region Forage/Beef Network (WFBN) (Copy of Proceedings attached).
9) Paper submitted to Canadian Journal of Plant Science with acknowledging BDF's funding.
10) Poster presentation in Soils and Crops 2001 (copy attached).

11) Listed as source of funding at the SPARC Annual Program Review, 2001.

References:

List of publications arising from this and/or related project:

1. Banerjee, M.R. and Schellenberg, M.P. 2000. The potential of legume-shrub mixtures for optimum forage production in Southwestern Saskatchewan. Canadian Journal of Plant Science (submitted).

2. Jefferson, P.G., Iwaasa, A.D., Schellenberg, M.P., Banerjee, M.R., and McLeod, J.G. 2000. Re-evaluation of native plant species for seeding on the semiarid prairie of western Canada. Canadian Journal of Plant Science (submitted).

3. Banerjee, M.R. and Schellenberg, M.P. 2001. Winterfat, saltbush - forage shrubs for the Canadian prairies. Proceedings of the Soils and Crops 2001, February 22-23, Saskatoon , Saskatchewan (in press).

4. Banerjee, M.R., and Schellenberg, M.P. 2000. Looking for legume-shrub mixture for optimum forage production. Forage-Ruminant Workshop Proceedings of the Symposium, pp. 14-24, July 20-21, Winnipeg, Manitoba.

5. Jefferson, P.G., Iwaasa, A.D., Schellenberg, M.P., Banerjee, M.R., and McLeod, J.G. 2000. Re-evaluation of native plant species for seeding on the semiarid prairie of western Canada. Forage-Ruminant Workshop Proceedings of the Symposium, pp. 54-71, July 20-21, Winnipeg, Manitoba.

6. Banerjee, M.R., and Schellenberg, M.P. 2000. Legume and native shrub mixtures for potential optimum forage production. Proceedings Soils & Crops 2000, pp. 447-455, February 24 & 25, Saskatoon, Saskatchewan.

7. Banerjee, M.R. and Schellenberg, M.P. 1999. Legume and native shrub mixtures – a potential for optimization of forage production. Agronomy Abstract, pp. 142, Annual Meeting, Crop Science Society of America, Oct. 31 - Nov. 4, Salt Lake City, Utah.

Technology Transfer:1. Jefferson, P.G., Iwaasa, A.D., Schellenberg, M.P., Banerjee, M.R., Selles, F. and McLeod, J.G. 2001. Current forage and grazing research at SPARC. South West Forage Association Annual Meeting. Swift Current, Saskatchewan, January 31, 2001.

2. Schellenberg, M.P., Banerjee, M.R., McLeod, J.G., Iwaasa, A. and Jefferson, P.G. 2000. Winterfat (*Kresheninnikovia lanata*) shrub research in the Canadian prairies. In: Pasture Ecology Newsletter. Issue no. 45, May 2000, U.K. pp. 2-3.

3. Iwaasa, A.D., Schellenberg, M., McLeod, J.G., Jefferson, P.G. and Banerjee, M.R. 2000.

What's new at the Swift Current Research Centre? In: Foraging into the Future: A conference looking at forage and livestock production in the next Millennium. Swift Current, Saskatchewan, Feb. 2-3, pp. 3.

4. Banerjee, M.R., Schellenberg, M.P. and Jefferson, P.G. 1999. Does saltbush occur in saltland? Agriculture and Agri-Food Canada (SPARC) Research Newsletter, No. 6.

5. Banerjee, M.R., Schellenberg, M.P. and Jefferson, P.G. 1999. Where do you look for winterfat? Agriculture and Agri-Food Canada (SPARC) Research Newsletter, No. 5.

Plot 1 **Wf** + Alf	**Plot 13** **Winterfat (Wf)**	Plot 25 Slt bsh + Alf	Plot 37 Alfalfa (Alf)
Plot 2 Slt bsh + Alf	Plot 14 Vetch	Plot 26 Slt bsh + Pr cl	**Plot 38** **Winterfat (Wf)**
Plot 3 **Winterfat (Wf)**	Plot 15 Alfalfa (Alf)	Plot 27 Alfalfa (Alf)	Plot 39 Slt bsh + Vetch
Plot 4 Slt bsh + Vetch	**Plot 16** *Control*	**Plot 28** **Wf** + Alf	Plot 40 Prairie clover (Pr cl)
Plot 5 **Wf** + Vetch	Plot 17 Salt bush (Slt bsh)	Plot 29 Prairie clover (Pr cl))	**Plot 41** **Wf** + Vetch
Plot 6 Vetch	Plot 18 Slt bsh + Alf	Plot 30 Slt bsh + Vetch	**Plot 42** *Control*
Plot 7 **Wf** + Pr cl	**Plot 19** **Wf** + Pr cl	**Plot 31** **Wf** + Pr cl	**Plot 43** **Wf** + Pr cl
Plot 8 Alfalfa (Alf)	**Plot 20** **Wf** + Vetch	**Plot 32** **Wf** + Vetch	Plot 44 Salt bush (Slt bsh)
Plot 9 Salt bush (Slt bsh)	Plot 21 Prairie clover (Pr cl)	**Plot 33** **Winterfat (Wf)**	Plot 45 Slt bsh + Pr cl
Plot 10 Prairie clover (Pr cl)	**Plot 22** **Wf** + Alf	Plot 34 Salt bush (Slt bsh)	Plot 46 Slt bsh + Alf
Plot 11 Slt bsh + Pr cl	Plot 23 Slt bsh + Pr cl	Plot 35 Vetch	Plot 47 Vetch
Plot 12 *Control*	Plot 24 Slt bsh + Vetch	**Plot 36** *Control*	**Plot 48** **Wf** + Alf

Figure 1. Experimental design of the legume-shrub field plot study

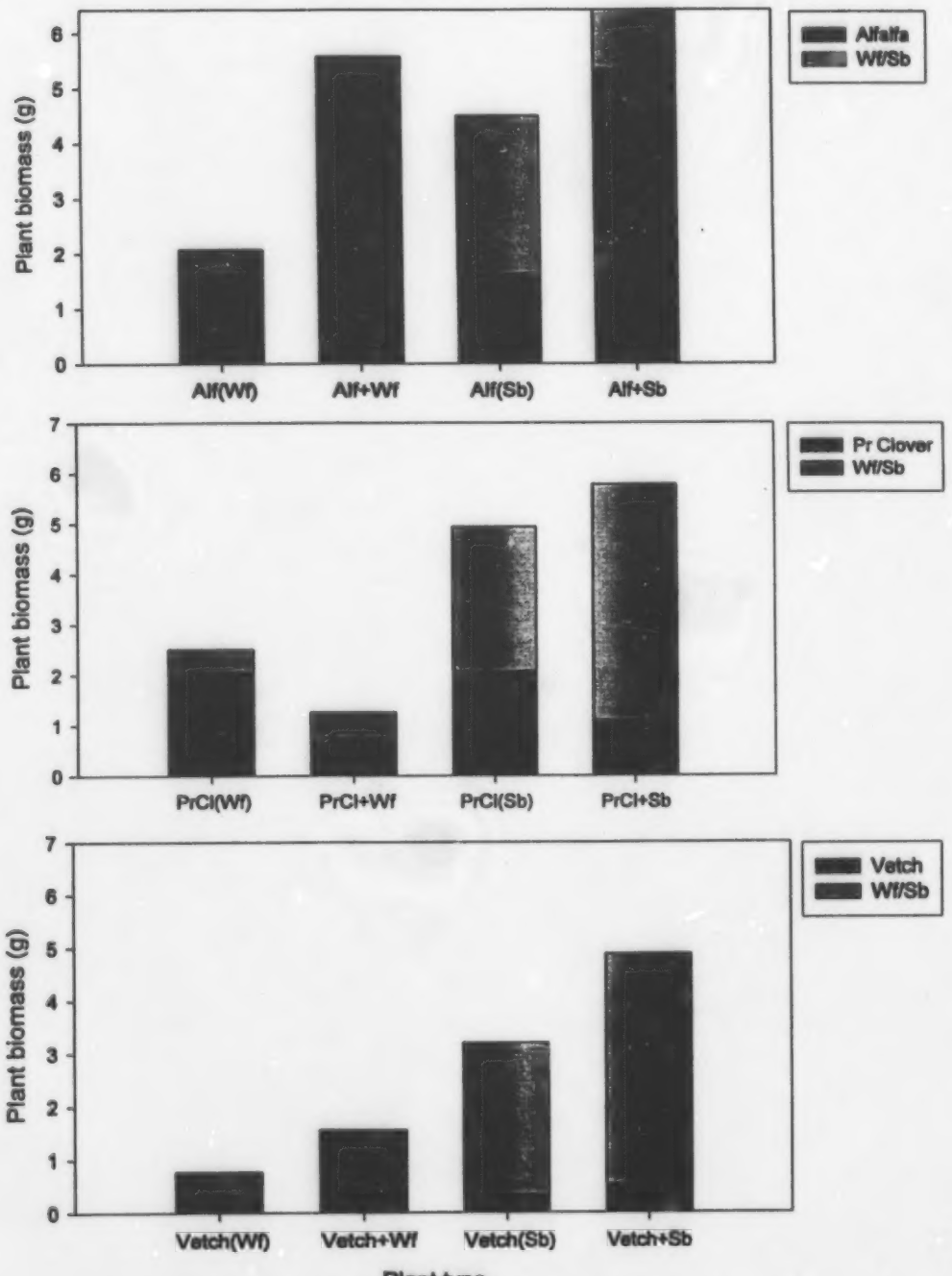

Figure 5. Fresh plant biomass in legume-shrub pot study

Table 1. Initial physical and chemical characteristics of South Farm soil at the legume-shrub study site in 1998.

Texture		Sandy loam
	Sand (%)	65.4
	Silt (%)	21.1
	Clay (%)	13.5
pH		6.61
EC (dS m^{-1})		0.54
Total C (g $100g^{-1}$)		1.93
Organic C (g $100g^{-1}$)		1.84
	Organic C as % of Total C	95.13
Total Nitrogen (g $100g^{-1}$)		0.2
	NH_4-N (.g g^{-1})	2.95
	NO_3-N (.g g^{-1})	1.76
C : N		9.84
Extractable P (.g g^{-1})		5.8
Extractable K (.g g^{-1})		457.54
Extractable S (.g g^{-1})		3.67

Table 2. Height of different plants of the legume-shrub field study at South Farm, Swift Current (1999)

Plant Height ± Standard Deviation (cm)				
Treatment Combination	Alfalfa	Prairie Clover	Winterfat	Saltbush
Alfalfa	31.3[a] ± 10.2			
Prairie Clover		8.0[a] ± 3.5		
Winterfat			9.3[a] ± 3.5	
Saltbush				5.3[a] ± 1.3
Alfalfa + Winterfat	34.5[b] ± 6.7		5.2[b] ± 1.9	
Prairie Clover + Winterfat		8.2[b] ± 3.1	11.8[b] ± 2.7	
Alfalfa + Saltbush	34.9[b] ± 8.1			7.2[b] ± 2.8
Prairie Clover + Saltbush		7.5[b] ± 2.8		7.7[b] ± 4.6

[a]Means are averages of 24 plants
[b]Means are averages of 12 plants

Table 3. Soil parameters after the 5th harvest in the legume-shrub pot study.

Treatment	Total C ($g\ 100\ g^{-1}$)	Organic C ($g\ 100\ g^{-1}$)	Total N ($g\ 100\ g^{-1}$)	NH_4-N ($g\ g^{-1}$)	NO_3-N ($g\ g^{-1}$)	Extract. P ($g\ g^{-1}$)	Ex (g
Control	1.58	1.55	0.16	3.03	32.31	12.89	
Alfalfa (Alf)	1.54	1.51	0.15	3.53	7.11	17.81	
Prairie clover (Pr Cl)	1.87	1.80	0.16	2.78	7.51	19.51	
Vetch	1.55	1.49	0.16	2.28	10.33	10.71	
Winterfat (Wf)	1.69	1.66	0.16	3.11	7.36	23.08	
Saltbush (Sb)	1.99	1.89	0.17	2.82	8.14	28.34	
Alf + Wf	1.62	1.58	0.16	7.44	7.05	13.11	
Alf + Sb	1.71	1.66	0.16	3.65	7.20	14.79	
Pr Cl + Wf	1.75	1.74	0.16	3.23	6.37	21.17	
Pr Cl + Sb	2.20	2.07	0.18	2.64	7.28	24.88	
Vetch + Wf	1.84	1.76	0.17	2.63	11.21	13.02	
Vetch + Sb	2.01	1.90	0.17	3.23	8.31	21.58	

Table 4. Soil physical and chemical characteristics under different vegetation in Grasslands National Park (GNP) and Prairie Farm Rehabilitation Administration (PFRA) sites.

Site	Vegetation	Texture	pH	EC (dS m-1)	Total C (g 100g-1)	Organic C (g 100g-1)	Organic C as % of Total C	Total N (g 100g-1)	C : N	NO_3-N ($g\,g^{-1}$)	Extractable P ($g\,g^{-1}$)	Extractable K ($g\,g^{-1}$)	Extractable S ($g\,g^{-1}$)
GNP	Salt bush	Loam	6.98	2.50	1.84	1.78	96.54	0.19	9.38	10.31	21.92	924.14	180.28
	Control	Loam	6.96	3.59	1.52	1.43	95.47	0.16	9.17	7.24	21.83	385.10	339.43
PFRA-1	Salt bush	Sandy loam	7.46	1.50	1.82	1.62	90.59	0.17	9.54	3.60	5.59	722.98	26.08
	Control	Sandy loam	7.56	1.17	1.54	1.44	93.59	0.15	9.77	2.12	4.36	325.38	24.76
PFRA-2	Salt bush	Loam	8.01	16.62	2.50	2.02	80.04	0.22	9.31	17.18	14.76	797.38	2431.30
	Control	Loam	7.83	11.75	2.69	2.17	78.96	0.24	9.03	22.11	19.38	543.00	1459.10
PFRA-3	Winterfat	Sandy clay loam	7.38	0.70	2.89	2.60	89.70	0.27	9.79	5.35	4.39	373.80	3.86
	Control	Sandy clay loam	6.93	0.56	3.13	2.99	95.96	0.30	10.20	2.91	4.54	330.95	3.06
PFRA-4	Wintefat	Sandy loam	6.96	0.70	2.81	2.47	87.94	0.27	9.27	5.06	8.12	579.29	8.87
	Control	Sandy loam	6.92	0.58	2.11	2.01	95.04	0.21	9.39	1.44	8.92	354.25	10.41

Table 5. Total dry matter weight of legumes and winterfat in the legume-shrub field study at South Farm, Swift Current for 2000.

Plant biomass (g)		
Treatment Combination	Alfalfa	Winterfat
Alfalfa	7180[a]	
Winterfat		43[b]
Alfalfa + Winterfat	6670[a]	9[b]
Prairie Clover[c] + Winterfat		31[b]
Alfalfa + Saltbush[c]	7040[a]	

[a]Values are total plant biomass of alfalfa from the four replicate plots

[b]Values are total plant biomass of winterfat from the four replicate plots

[c] Saltbush and Purple Prairie Clover yields not measurable

Table 6. Forage quality analysis for alfalfa and winterfat in the legume-shrub field study at South Farm, Swift Current in 2000.

Plant species in combination	Crude protein (%)	Total P (%)	Total Ca (%)	OMD (%)	ADF (%)	NDF (%)
Alfalfa monoculture	16.39	0.18	15.24	56.60	33.54	39.98
Winterfat monoculture	na	na	na	na	26.25	40.00
Alfalfa in Alf+Wf combination	16.83	0.19	17.03	56.26	33.92	40.81
Winterfat in Alf+Wf combination	na	na	na	na	24.54	35.93
Alfalfa in Alf+Sb combination	15.78	0.17	15.58	55.62	34.95	42.22
Winterfat in Wf+Pr cl combination	na	na	na	na	29.51	42.02

na - insufficient sample for full chemical determination

Table 7. Soil parameters in the legume-shrub field-plot study during year 1999 after two years of the study.

Treatment	pH	EC ($dS\ m^{-1}$)	Total C ($g\ 100\ g^{-1}$)	Organic C ($g\ 100\ g^{-1}$)	Organic C as % of Total C	Total N ($g\ 100\ g^{-1}$)	C:N	NH_4-N ($\mu g\ g^{-1}$)	NO_3-N ($\mu g\ g^{-1}$)	Extract. P ($\mu g\ g^{-1}$)	Extract. K ($\mu g\ g^{-1}$)	Extract. S ($g\ g^{-1}$)
Control	6.25	0.27	2.15	2.12	98.65	0.23	9.30	6.35	6.64	7.27	428.44	2.77
Alfalfa (Alf)	6.34	0.29	2.16	2.12	98.47	0.23	9.33	5.32	7.63	7.47	445.03	2.88
Prairie clover (Pr Cl)	6.34	0.33	2.19	2.15	98.04	0.23	9.32	4.85	11.20	10.1	488.24	3.26
Winterfat (Wf)	6.35	0.32	2.07	2.04	98.69	0.22	9.38	4.29	9.61	9.37	397.32	3.18
Alf + Wf	6.28	0.28	2.09	2.06	98.76	0.22	9.57	6.93	6.60	8.92	475.45	3.61
Pr Cl + Wf	6.15	0.28	2.16	2.14	98.84	0.23	9.39	6.48	11.20	9.80	358.79	2.91

Table 8. Soil parameters in the legume-shrub field-plot study during year 2000 after three years of the study.

Treatment	pH	EC ($dS\ m^{-1}$)	Total C ($g\ 100\ g^{-1}$)	Organic C ($g\ 100\ g^{-1}$)	Organic C as % of Total C	Total N ($g\ 100\ g^{-1}$)	C:N	NH_4-N ($\mu g\ g^{-1}$)	NO_3-N ($\mu g\ g^{-1}$)	Extract. P ($\mu g\ g^{-1}$)	Extract. K ($\mu g\ g^{-1}$)	Extract. S ($\mu g\ g^{-1}$)
Control	6.29	0.18	1.82	1.80	98.55	0.19	9.33	1.13	2.61	3.06	363.90	1.58
Alfalfa (Alf)	6.27	0.21	1.84	1.81	98.25	0.19	9.41	0.66	2.76	2.60	295.83	1.44
Prairie clover (Pr Cl)	6.48	0.23	1.96	1.93	98.31	0.20	9.53	0.76	2.92	2.81	437.57	1.57
Winterfat (Wf)	6.43	0.22	1.80	1.77	98.33	0.19	9.21	0.93	2.66	2.01	311.42	1.7
Alf + Wf	6.14	0.18	1.90	1.81	95.54	0.19	9.42	0.89	3.24	2.97	392.79	1.55
Pr Cl + Wf	6.26	0.20	1.97	1.93	97.78	0.20	9.86	0.63	3.30	2.53	343.22	1.62